Diffraction: from HERA and LHC to the EIC

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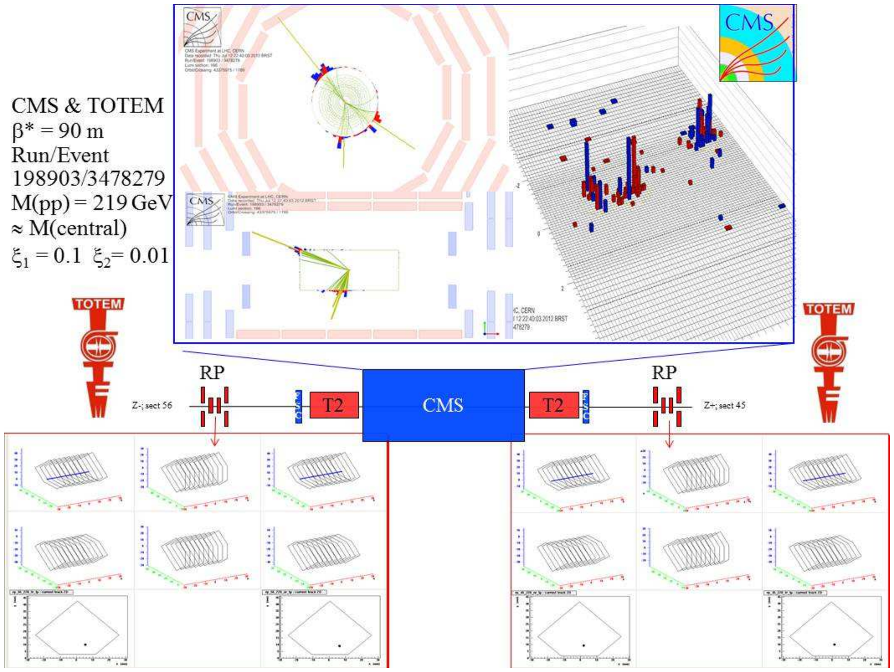
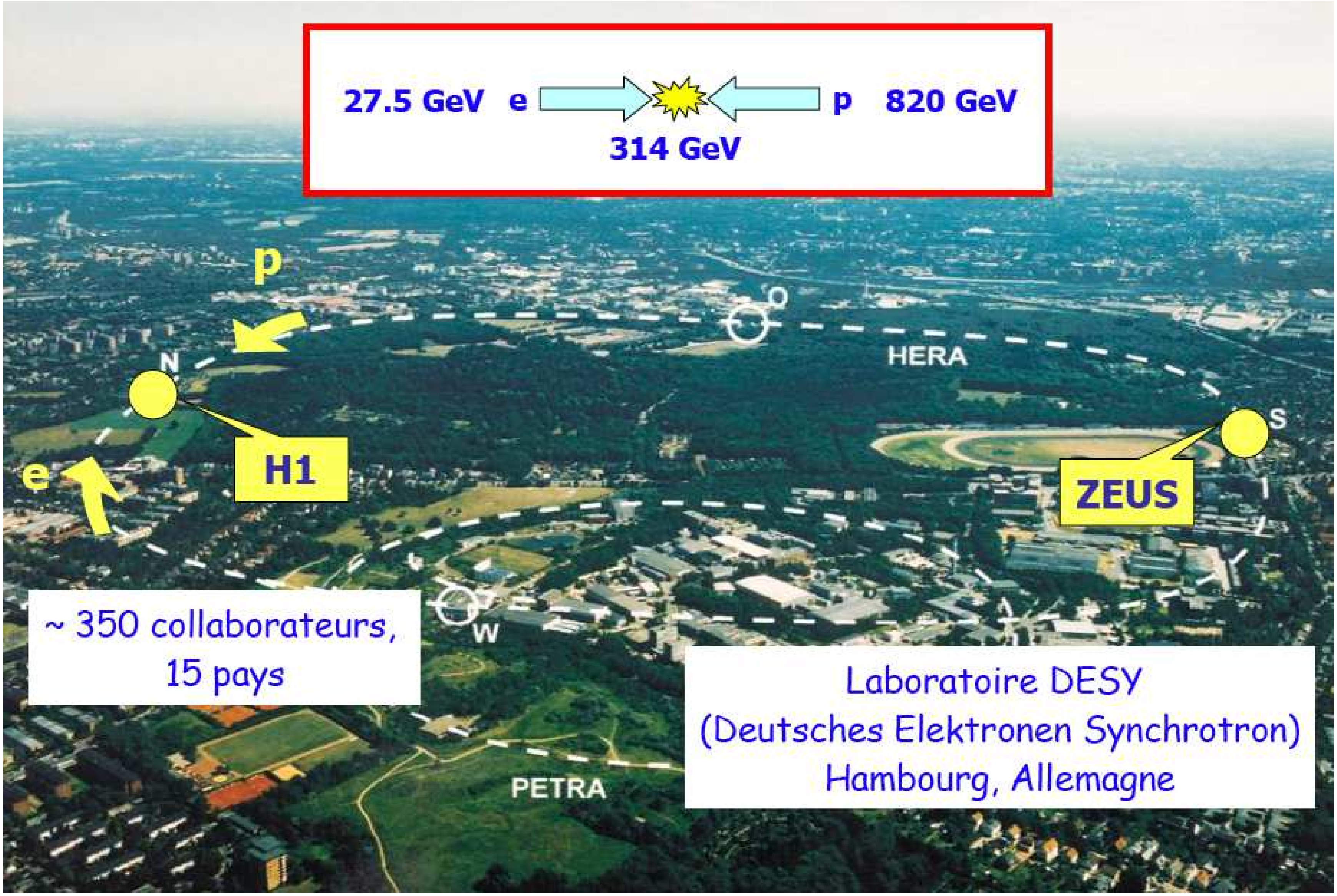


Contents:

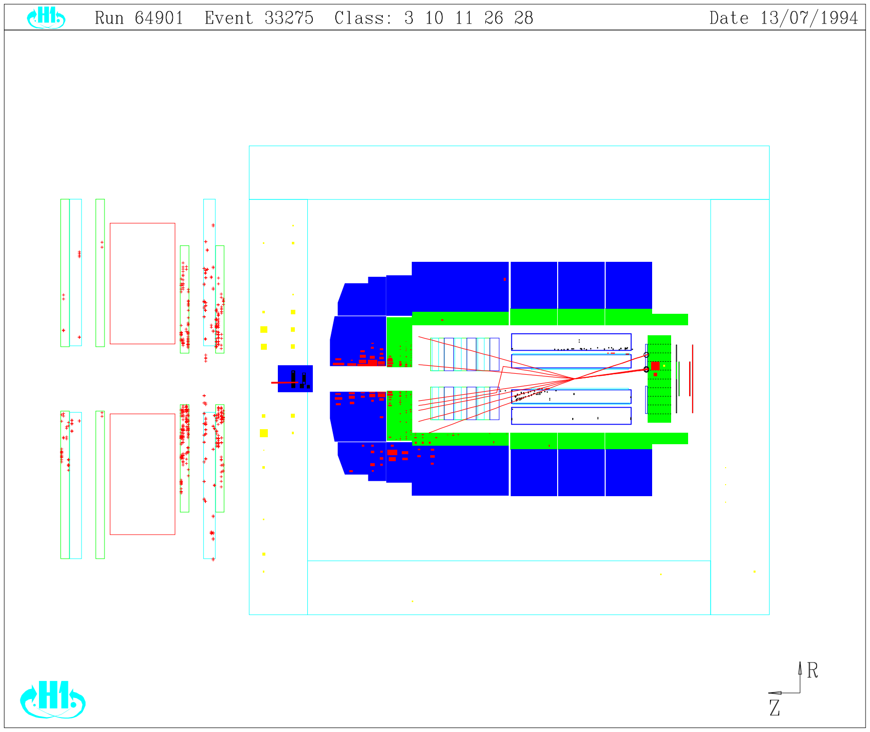
- Diffraction at HERA
- Vector meson production
- PDFs in Pomeron
- Factorization breaking
- NB: a few topics only discussed in this short talk

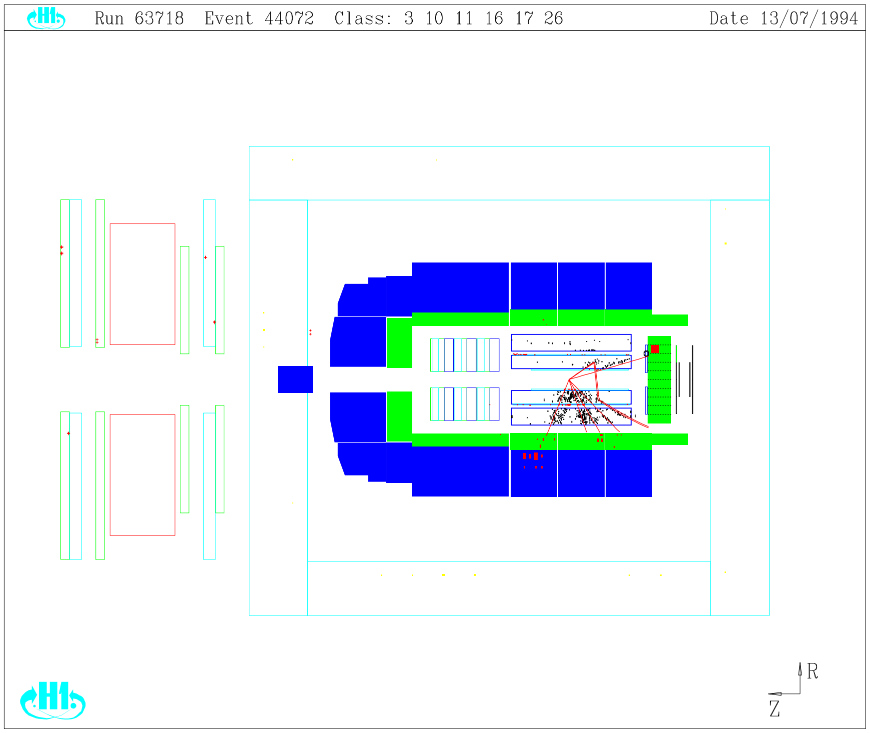
The HERA accelerator at DESY, Hamburg

HERA: ep collider who closed in 2007, about 1 fb^{-1} accumulated

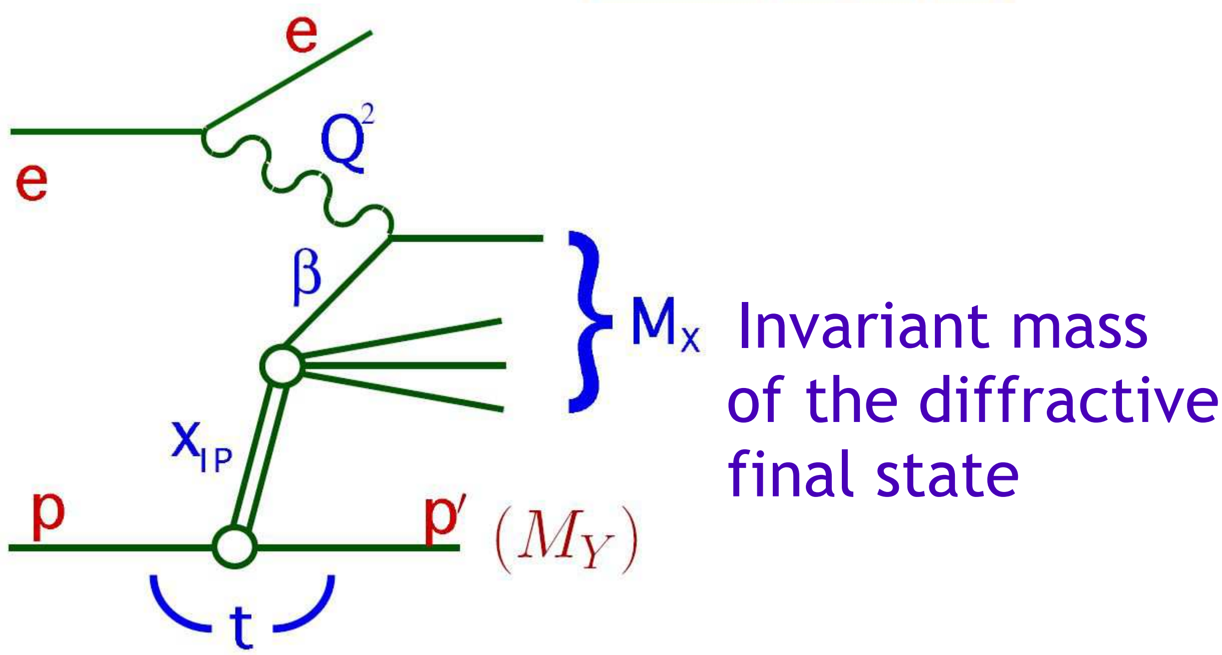


DIS and Diffractive event at HERA





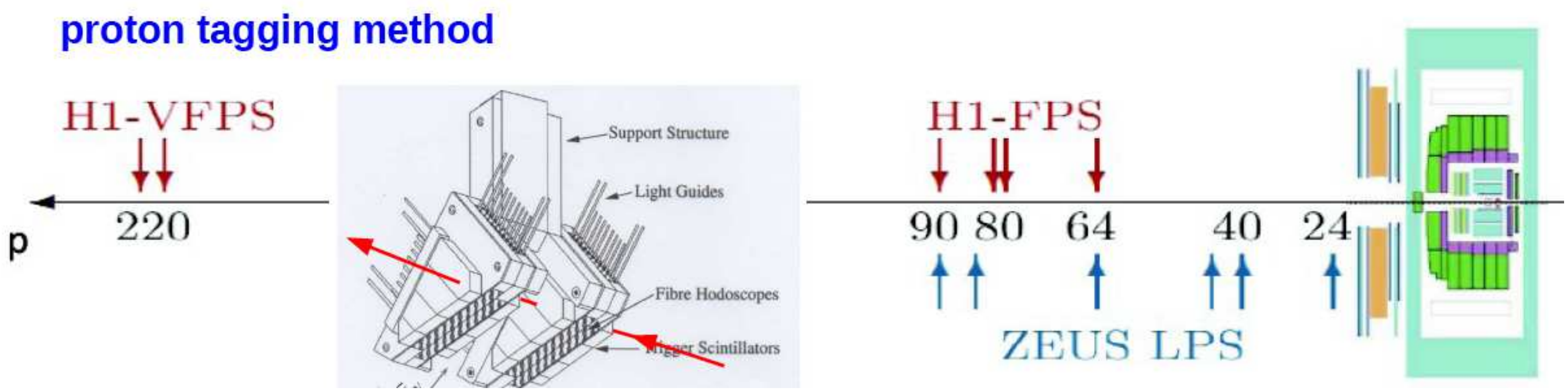
Diffractive kinematical variables

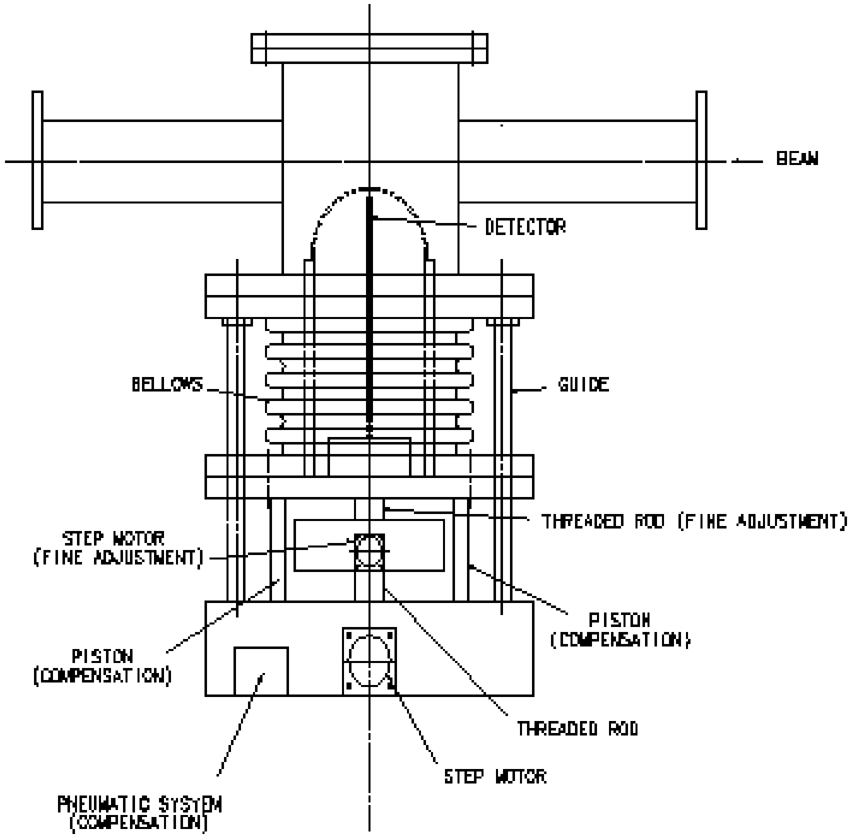


- Momentum fraction of the proton carried by the colourless object (pomeron): $x_p = \xi = \frac{Q^2+M_X^2}{Q^2+W^2}$
- Momentum fraction of the pomeron carried by the interacting parton if we assume the colourless object to be made of quarks and gluons: $\beta = \frac{Q^2}{Q^2+M_X^2} = \frac{x_{Bj}}{x_P}$
- 4-momentum squared transferred: $t = (p - p')^2$

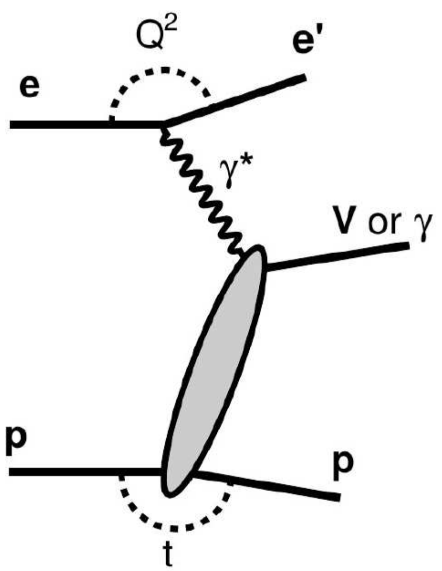
Proton tagging method

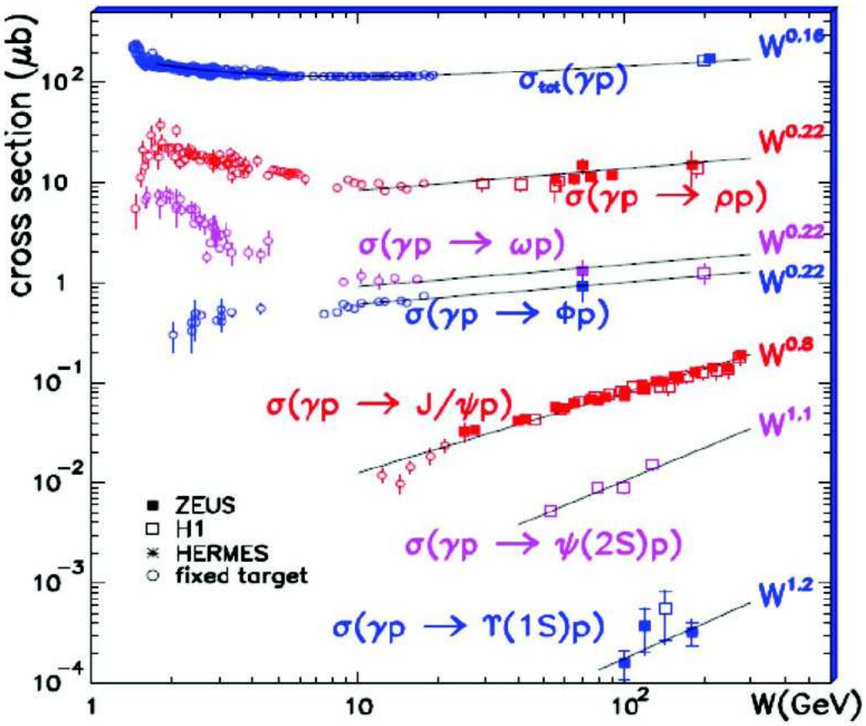
- 1st selection of diffractive events: Rapidity gaps
- 2nd definition of diffraction: Tag protons in roman pots
- M_X method: Diffractive component is exponentially suppressed





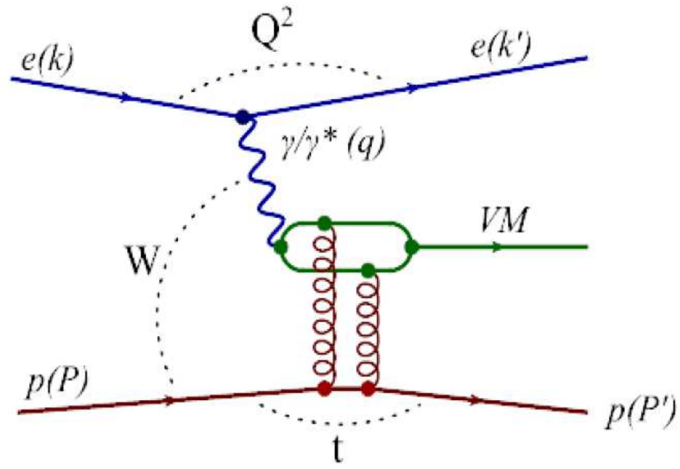
Vector meson production

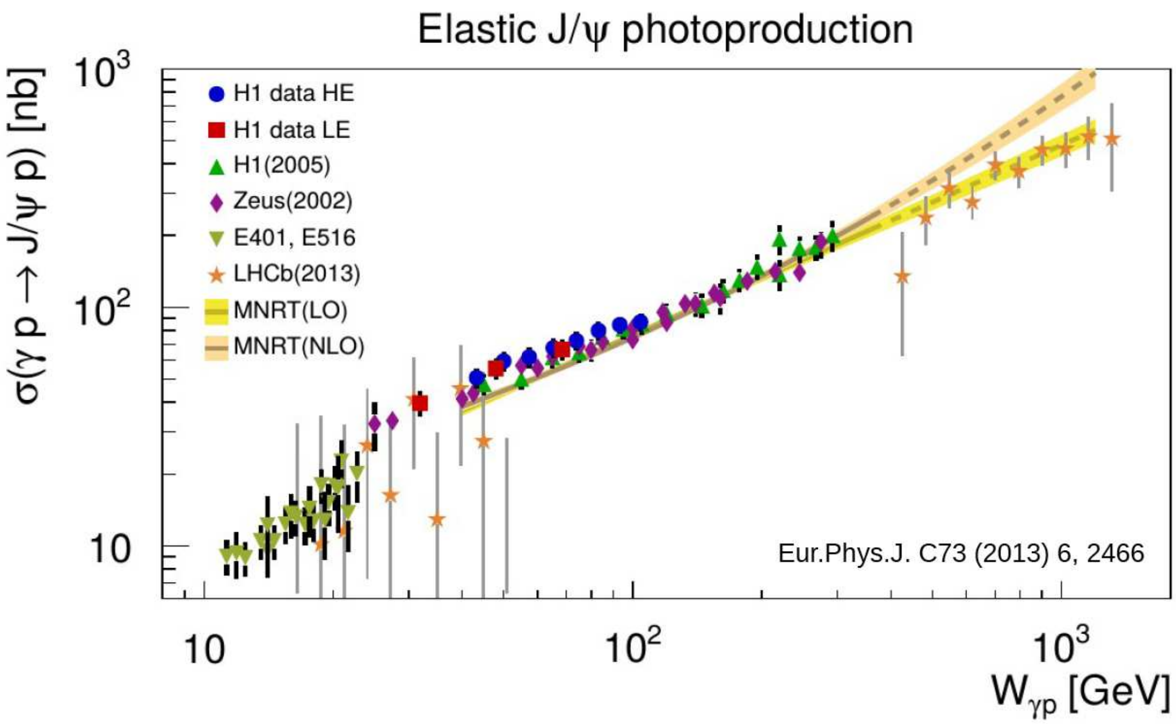




- Vector meson production and Deeply Virtual Compton Scattering (DVCS): ρ, ω, Φ, ρ', J/Ψ, γ...
- Study the transition between soft and hard physics: $\sigma^{\gamma p \to Vp} \sim (W^2)^{2\alpha_P(t)-2}$ with $\alpha_P(t) = \alpha_P(0) + \alpha' t$.
- Donnachie Landshoff: $\alpha_P(0) \sim 1.085$, $\Upsilon(1S)$: $\alpha_P(0) \sim 1.6$
- Vector meson production to be studied at the EIC in order to extract GPDs
- Large momentum transfer t probes small impact parameter where the parton density is large: different energy dependence with/without saturation

An example: J/Ψ in photoproduction



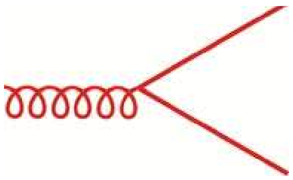


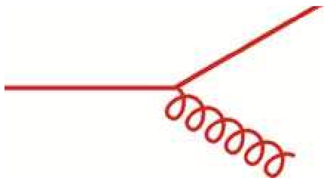
- Hard scale present due to J/Ψ mass ($Q^2 \sim 0$)
- Description using perturbative QCD and dipole model: Pomeron is modeled by a gluon ladder at lowest order: $\sigma \sim [\alpha_S(\mu^2) x g(x, \mu^2)]^2$

Measurement of the diffractive structure function F_2^D

- Measurement of the diffractive cross section using the rapidity gap selection over a wide kinematical domain in (x_P, β, Q^2) (same way as F_2 is measured, there are two additional variables for diffraction)
- Use these data to make QCD fits using NLO Dokshitzer Gribov Lipatov Altarelli Parisi evolution equation and determine the pomeron structure in quarks and gluons: $\rightarrow$ allows to predict inclusive diffraction at Tevatron/LHC
- At low β: evolution driven by $g \rightarrow q\bar{q}$, at high β, $q \rightarrow qg$ becomes important
- Take all data for $Q^2 > 8.5$ GeV^2, $\beta < 0.8$ to be in the perturbative QCD region and avoid the low mass region (vector meson resonances)

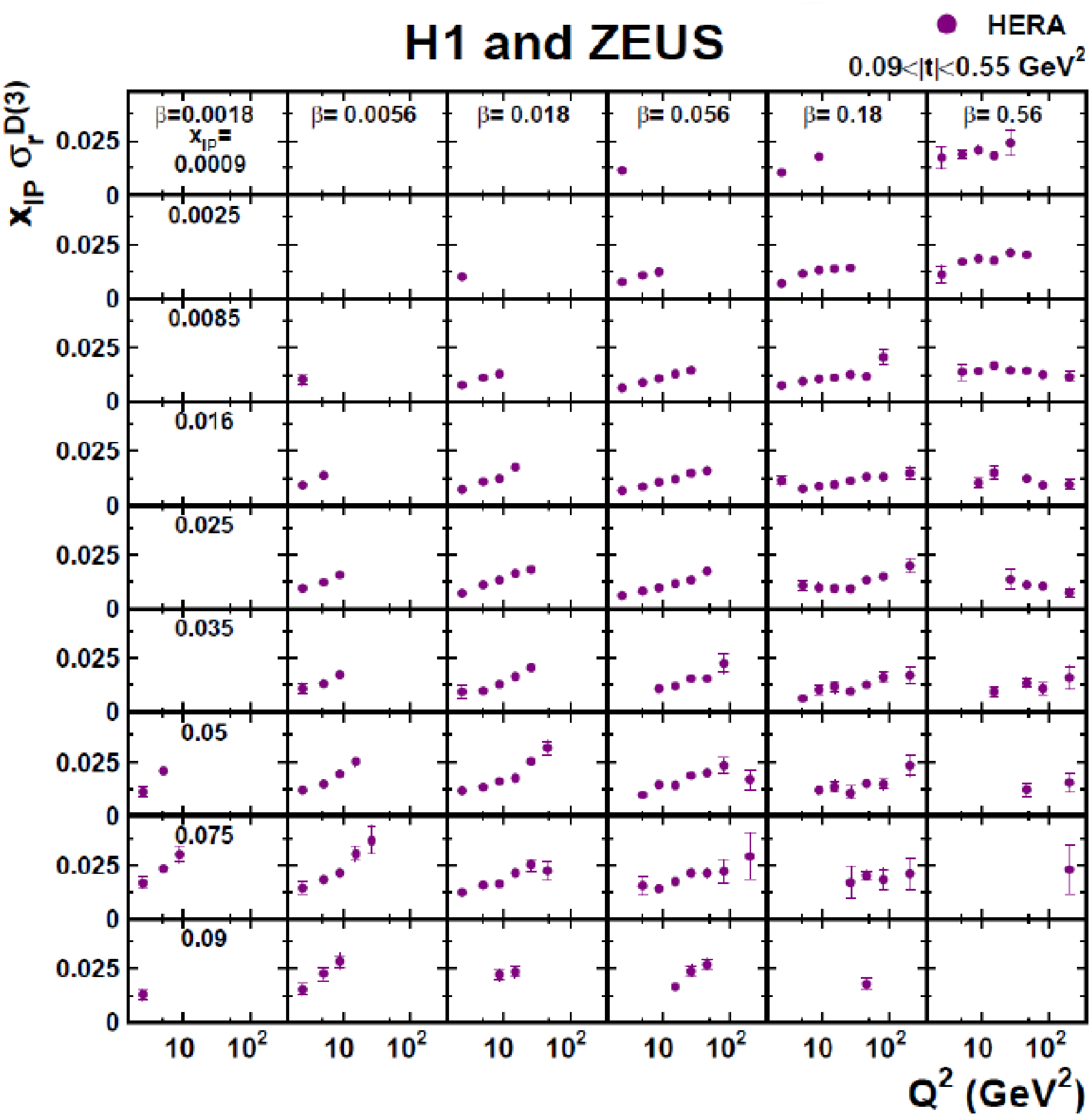
$$\frac{dF_2^D}{d\log Q^2} \sim \frac{\alpha_S}{2\pi} \left[P_{qg} \otimes g + P_{qq} \otimes \Sigma\right]$$





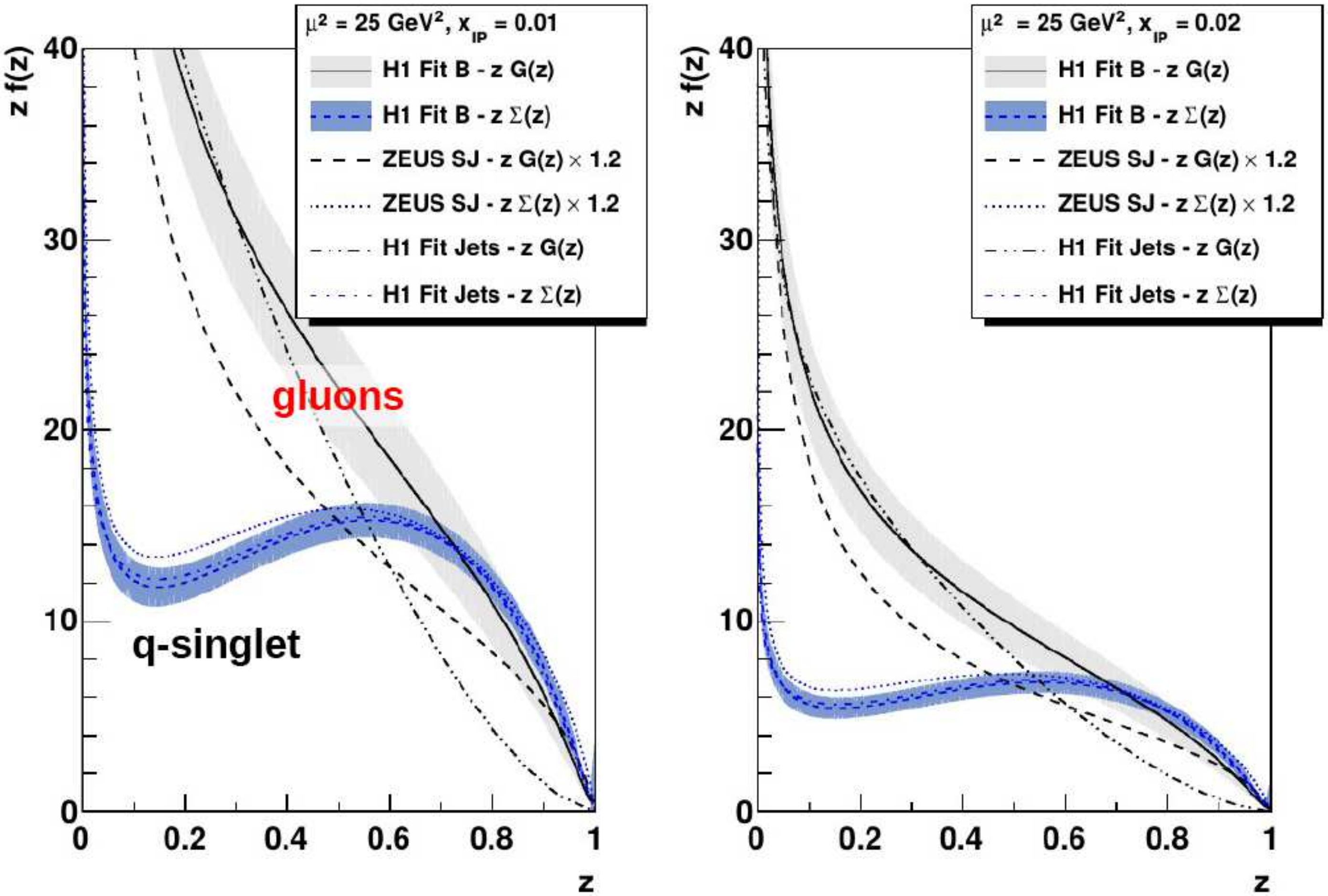
Diffractive structure function

Combine H1 and ZEUS measurements: $\sigma_r = F_2^D - \frac{y^2}{1+(1-y)^2} F_L^D$



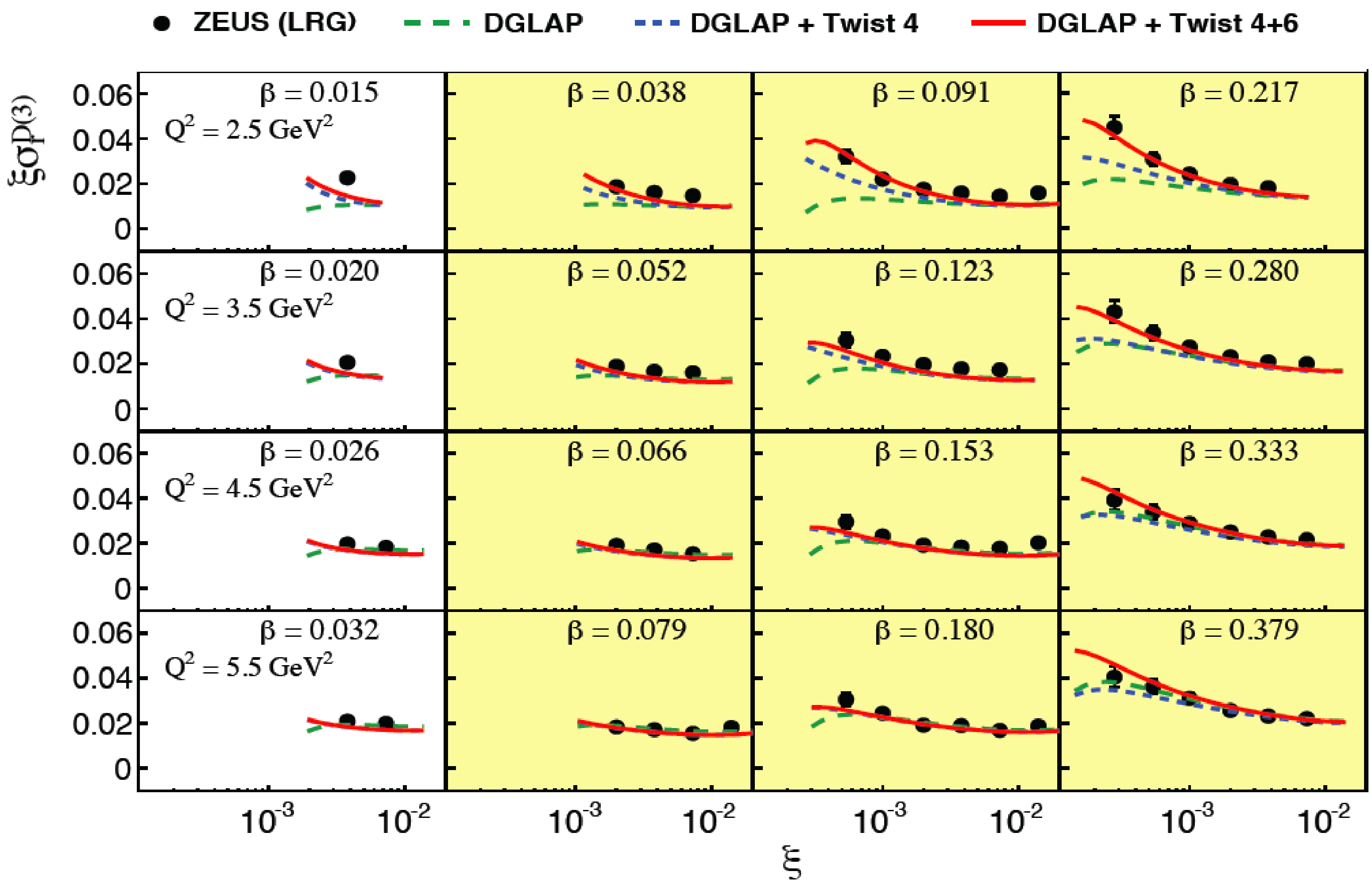
Parton distributions

- Determination of quark and gluon densities in Pomeron: Pomeron is gluon dominated
- Reduce uncertainties of PDFs, alternative models: resolved pomerons...
- Important to get a better understanding of PDFs at the EIC



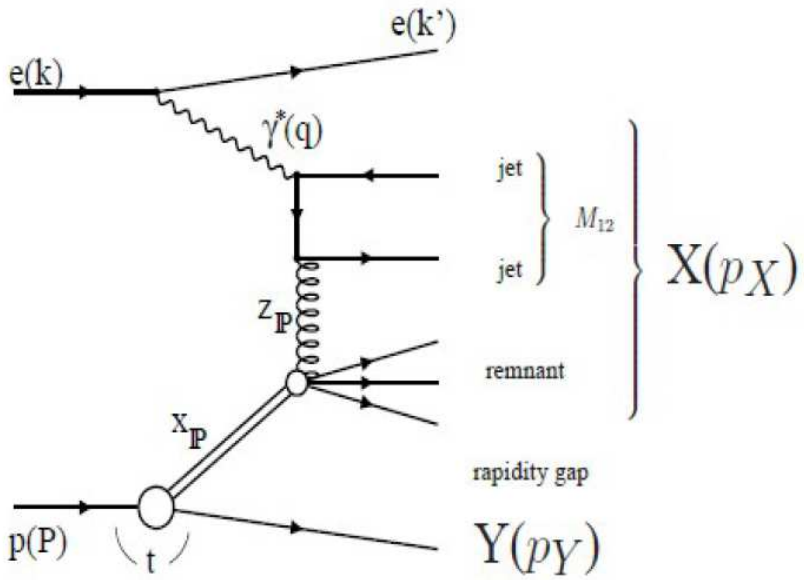
Higher twist contributions

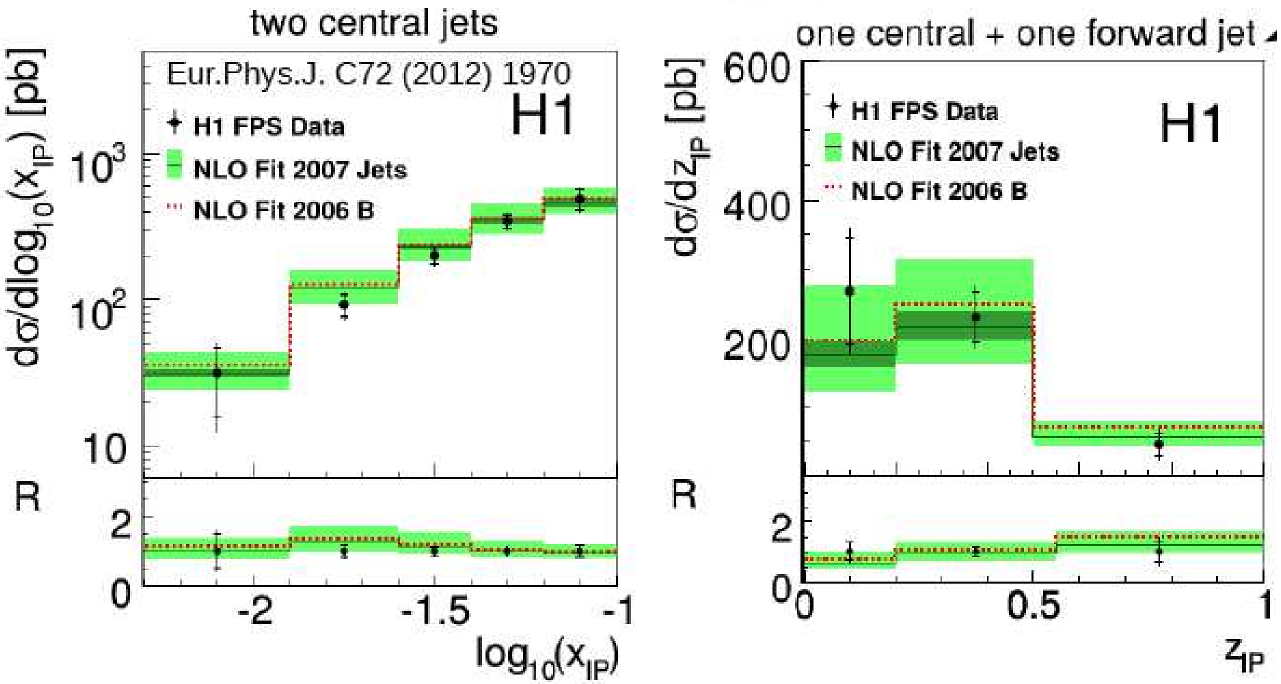
- Diffractive data at HERA cannot be described at low Q^2: higher twists 4 and 6 evaluated by dipole saturation model (Motyka, Sadzikowski, Slaminski)
- Improves the fit at low Q^2, can be further studied at the EIC: dependence on A, energy...



Jet production in diffraction

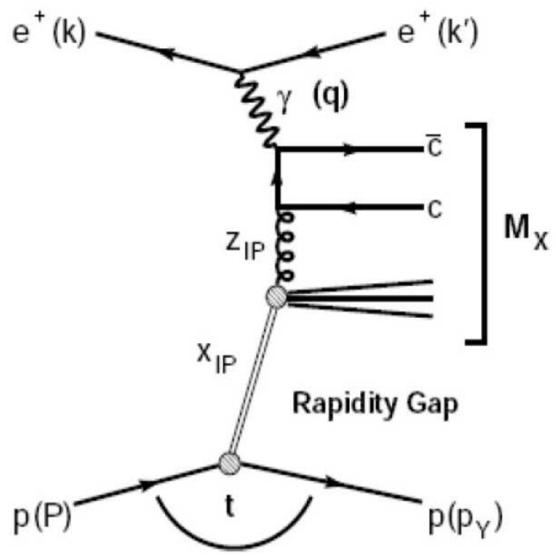
Dijet production adds constraints on the Pomeron PDFs, check on model consistency

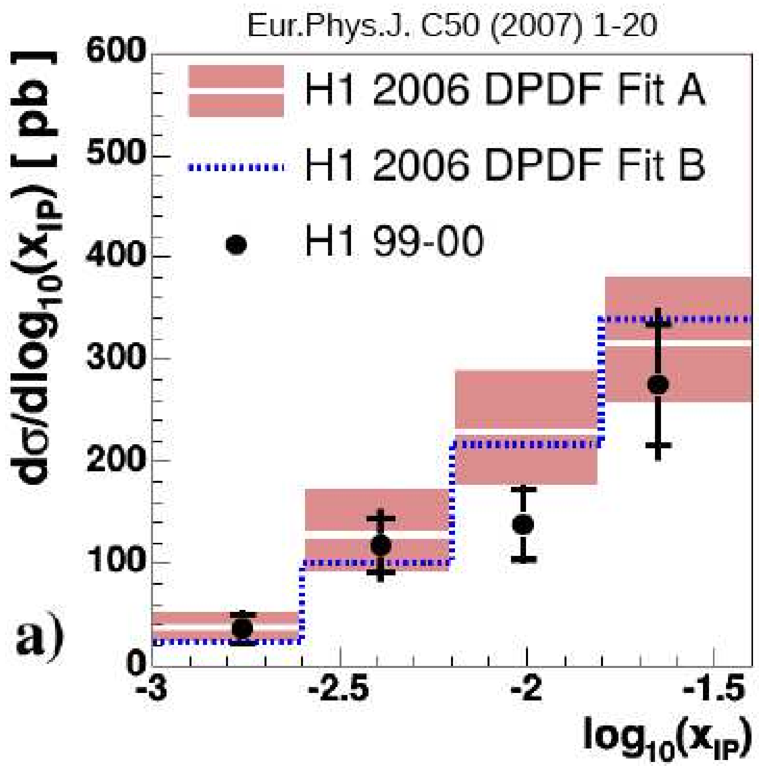


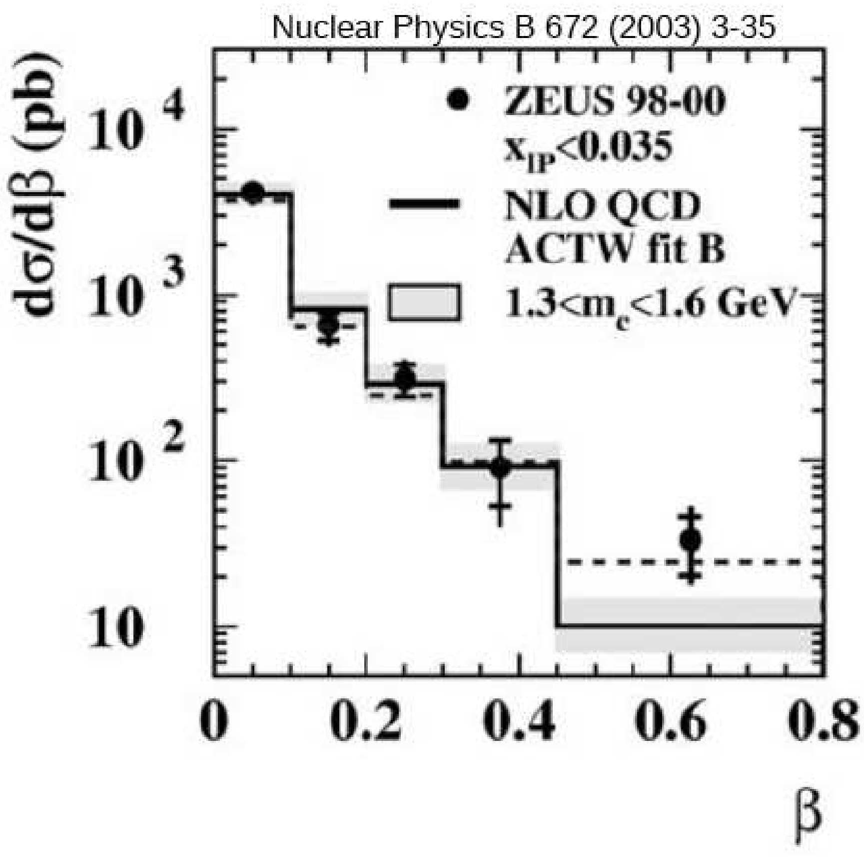


Open charm

Same cross check using charm and beauty production

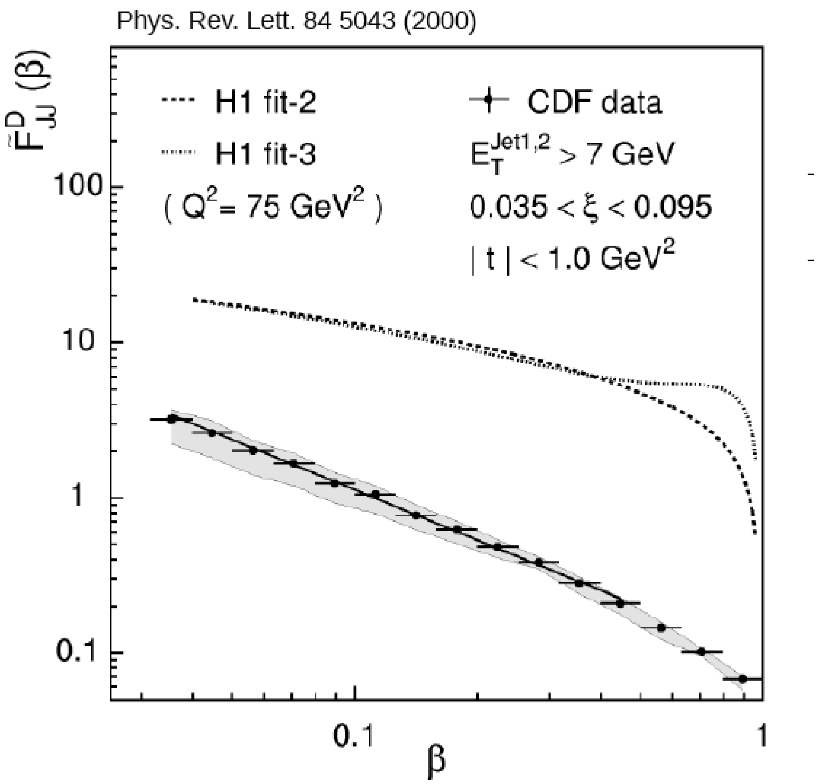


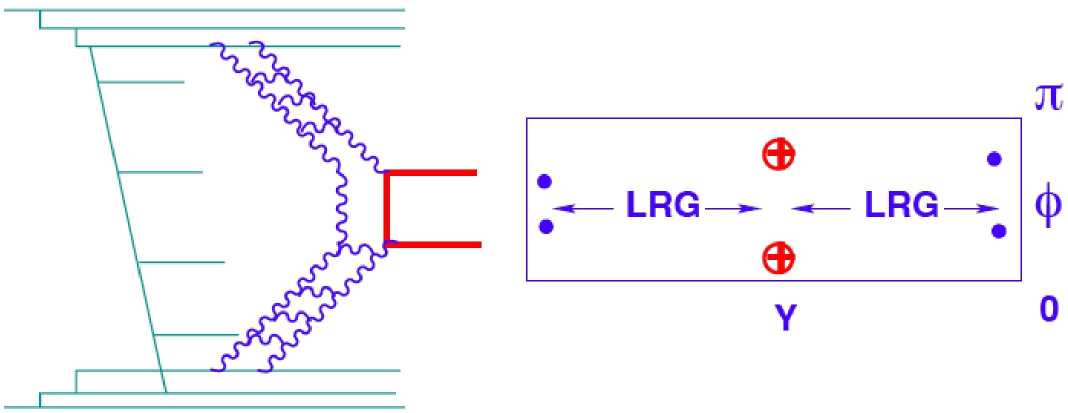




Factorization breaking between ep and pp

- Comparison between Tevatron CDF data and extrapolations from HERA
- Discrepancy due to survival probability



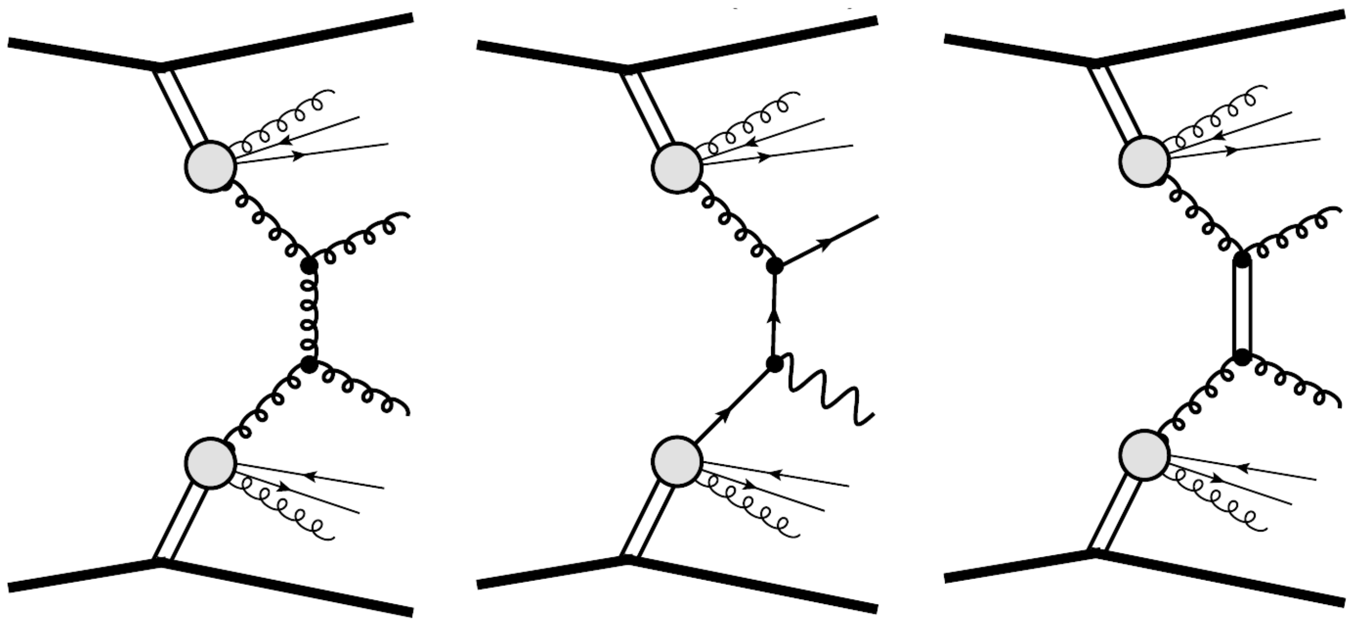


a)

b)

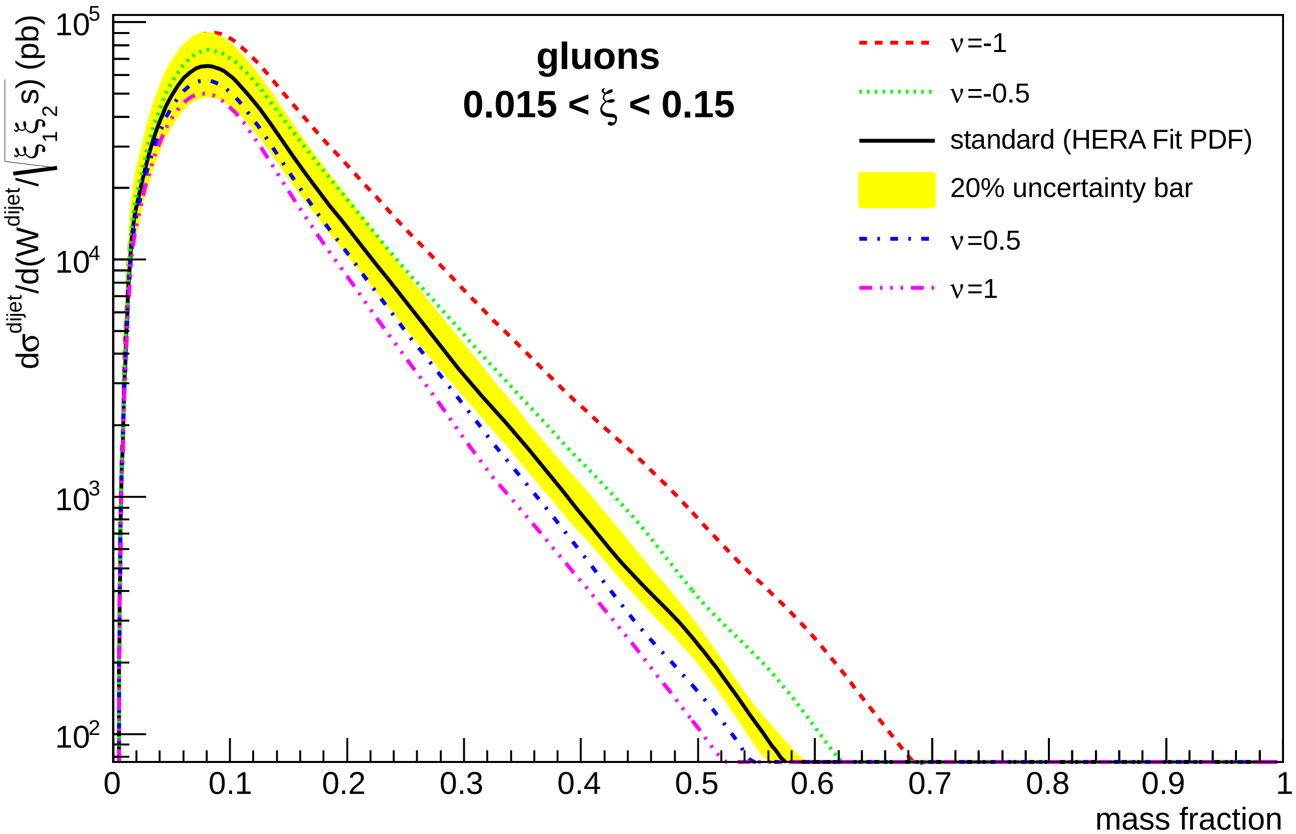
Hard diffraction at the LHC

- Dijet production: dominated by gg exchanges; γ+jet production: dominated by qg exchanges
- Jet gap jet in diffraction: Probe BFKL
- Three aims
  - Is it the same object which explains diffraction in pp and ep?
  - Further constraints on the structure of the Pomeron as was determined at HERA
  - Survival probability: difficult to compute theoretically, needs to be measured, inclusive diffraction is optimal place for measurement



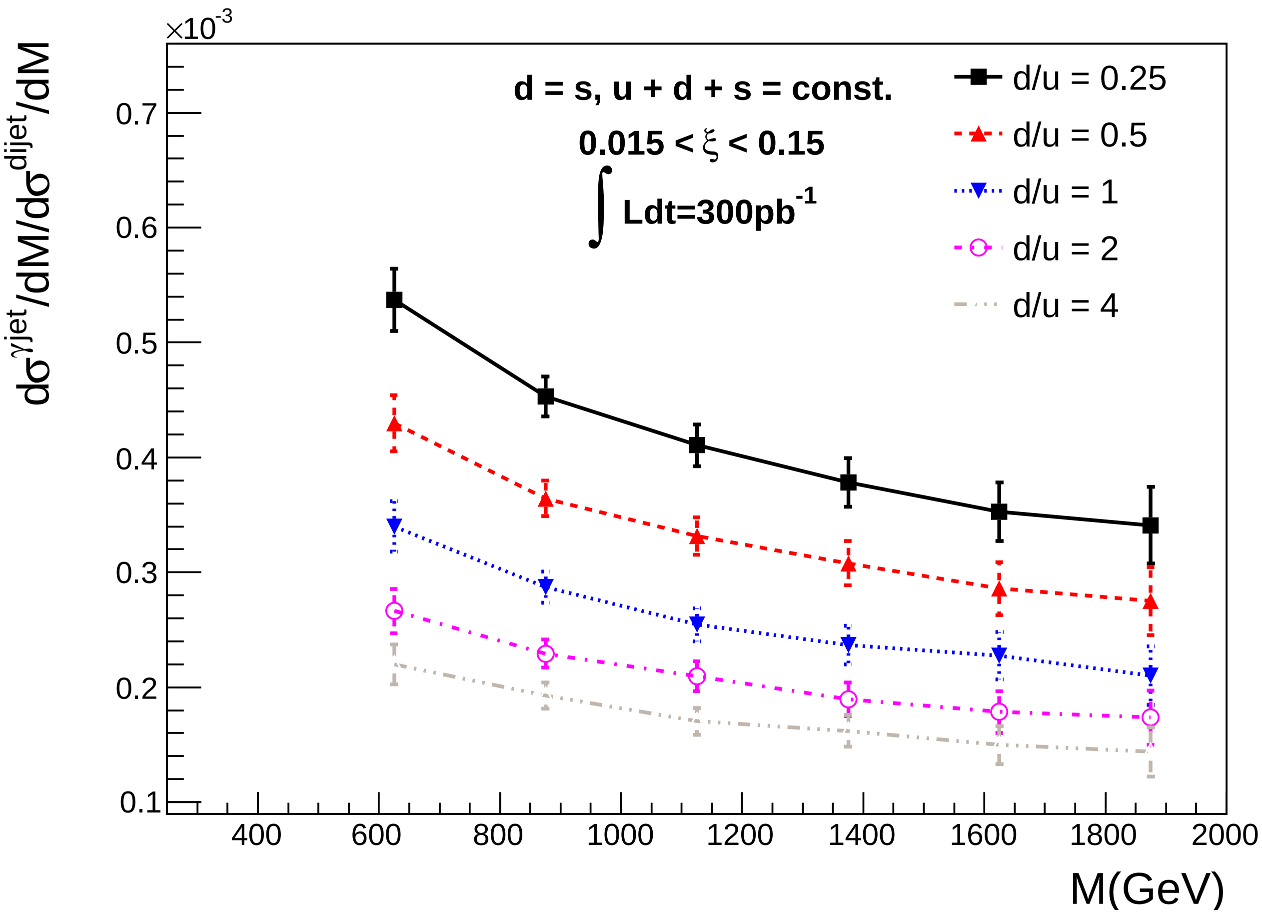
Inclusive diffraction at the LHC: sensitivity to gluon density

- Predict DPE dijet cross section at the LHC in AFP acceptance, jets with p_T >20 GeV, reconstructed at particle level using anti-k_T algorithm
- Sensitivity to gluon density in Pomeron especially the gluon density on Pomeron at high β: multiply the gluon density by $(1-\beta)^\nu$ with $\nu = -1, ..., 1$
- Dijet mass fraction: dijet mass divided by total diffractive mass ($\sqrt{\xi_1 \xi_2 S}$)



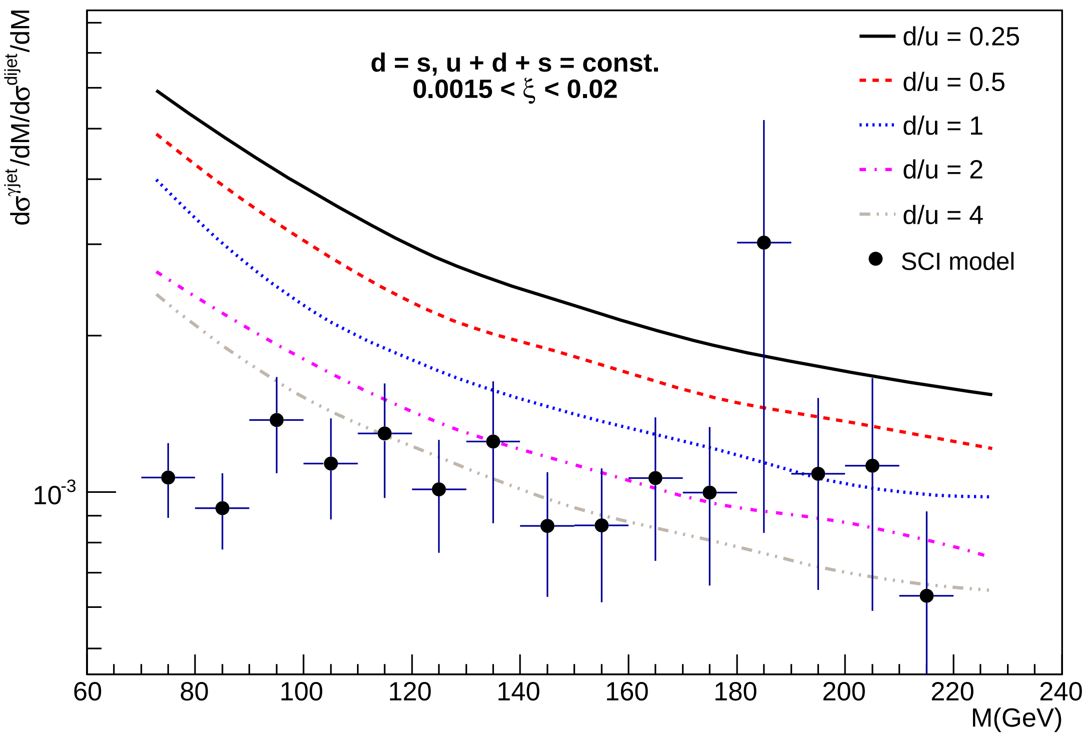
Inclusive diffraction at the LHC: sensitivity to quark densities

- Predict DPE γ+jet divided by dijet cross section at the LHC
- Sensitivity to universality of Pomeron model
- Sensitivity to quark density in Pomeron, and of assumption: $u = d = s = \bar{u} = \bar{d} = \bar{s}$ used in QCD fits at HERA
- Measurement of W asymmetry also sensitive to quark densities



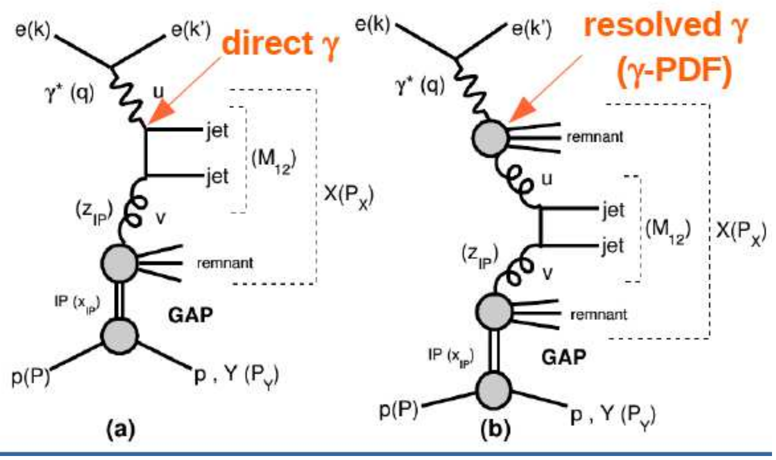
Diffraction at the LHC: sensitivity to soft colour interaction models

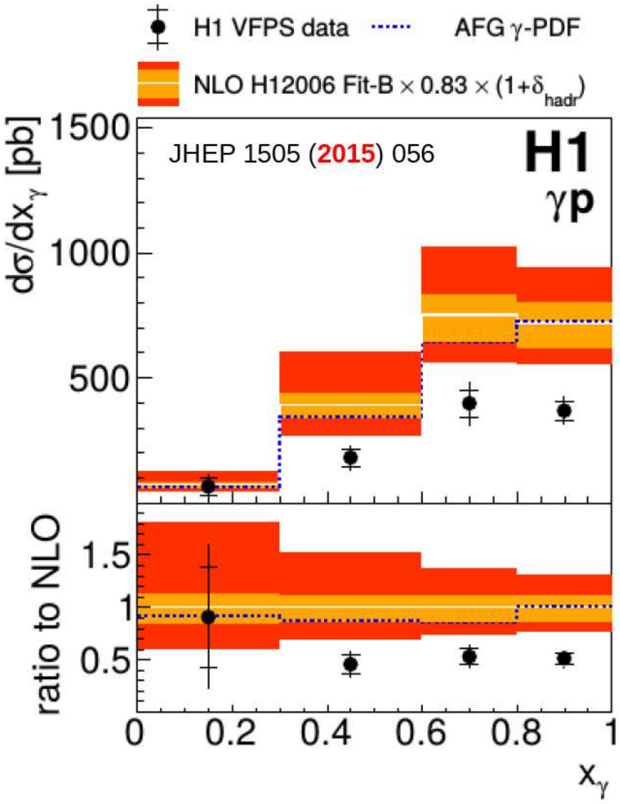
- Alternative model to explain diffraction: Soft Colour Interaction (R.Enberg, G.Ingelman, N.Timneanu, hep-ph/0106246); Variation of colour string topologies, giving a unified description of final states for diffractive and non-diffractive events
- Predict DPE γ+jet divided by dijet cross section at the LHC for pomeron like and SCI models
- In particular, the diffractive mass distribution (the measurement with lowest systematics) allows to distinguish between the two sets of models: flat distribution for SCI

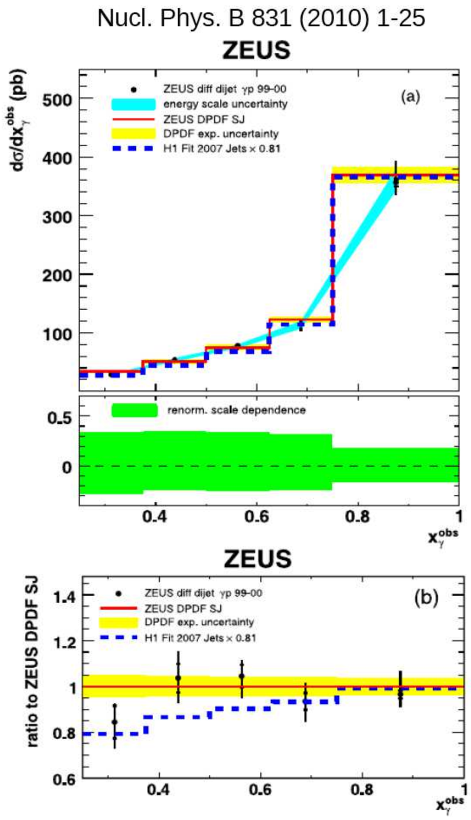


Factorization studies at HERA in Photoproduction

- Factorization is not expected to hold for resolved γ
- Situation unclear: Observed by H1 but not by ZEUS



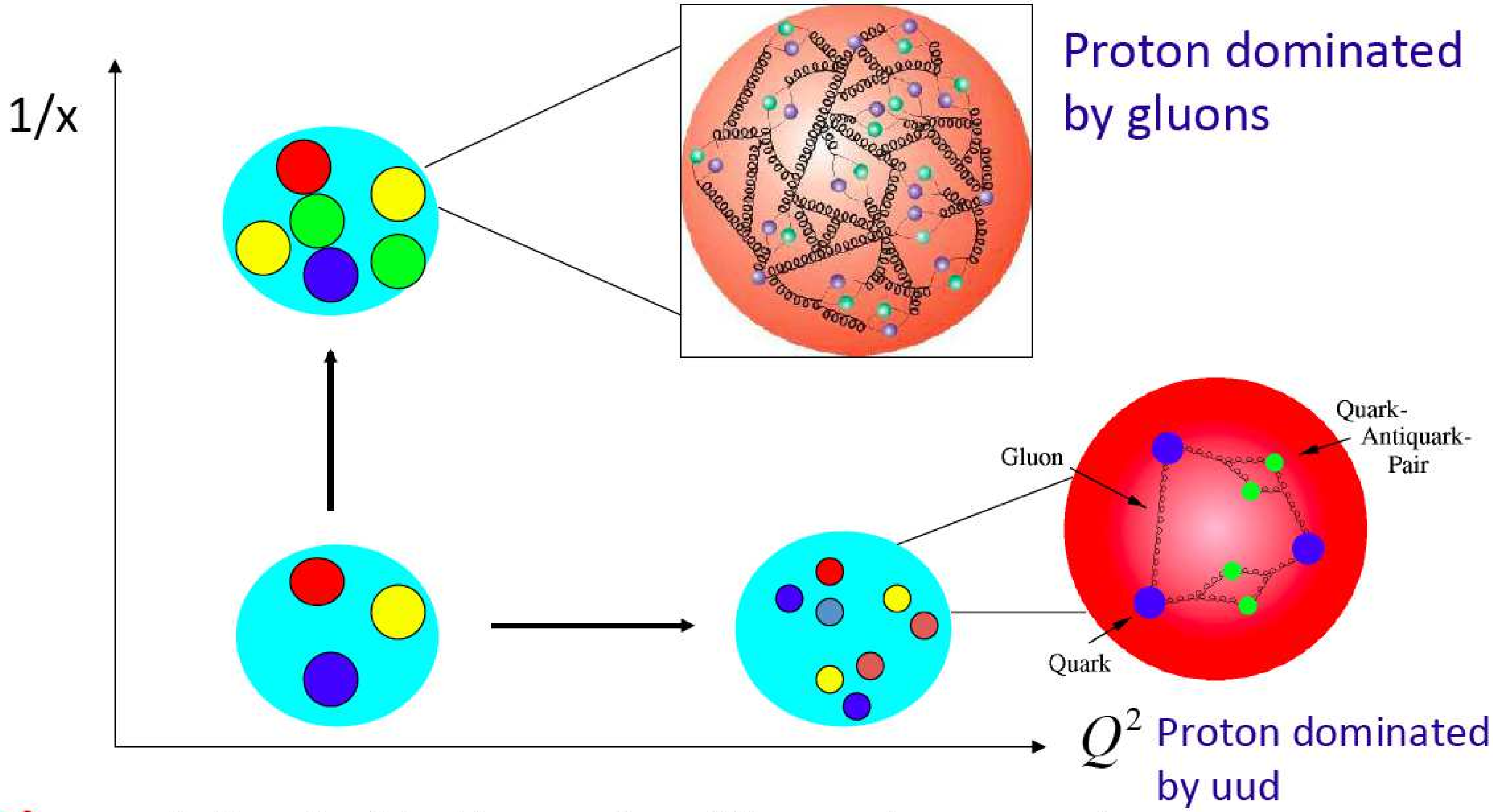




Looking for BFKL effects

- Dokshitzer Gribov Lipatov Altarelli Parisi (DGLAP): Evolution in Q^2
- Balitski Fadin Kuraev Lipatov (BFKL): Evolution in x

Aim: Understanding the proton structure (quarks, gluons)

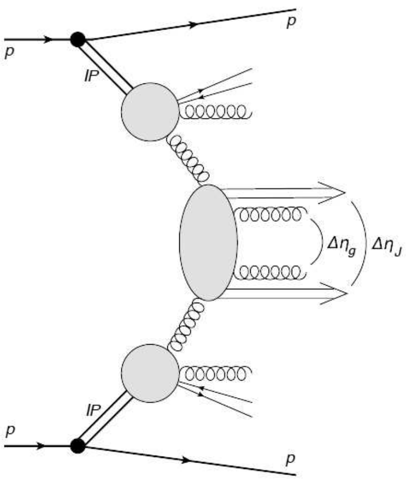


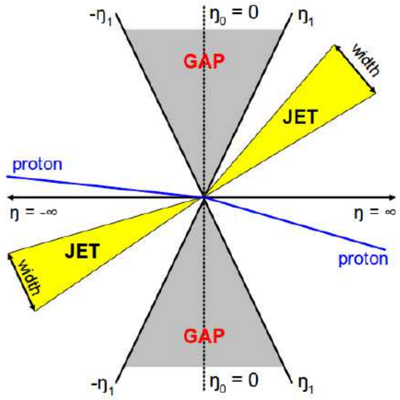
Q^2 : resolution inside the proton (like a microscope)

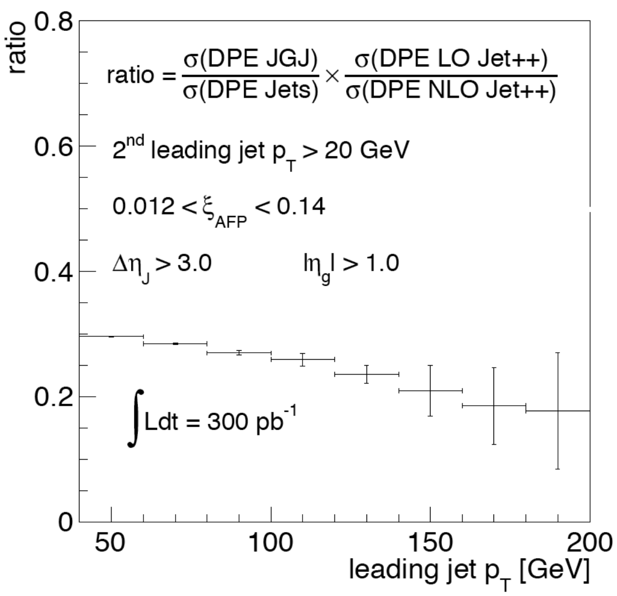
X :Proton momentum fraction carried away by the interacting quark

Jet gap jet events in diffraction

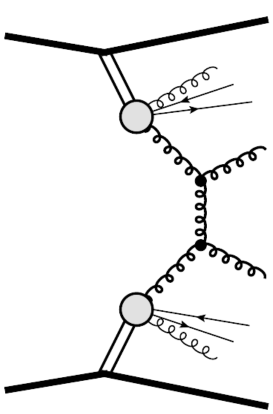
- Jet gap jet events in DPE processes: clean process, allows to go to larger $\Delta\eta$ between jets
- See: Gaps between jets in double-Pomeron-exchange processes at the LHC, C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, Phys. Rev. D 87 (2013) 034010
- Can be studied at EIC: gaps between jets

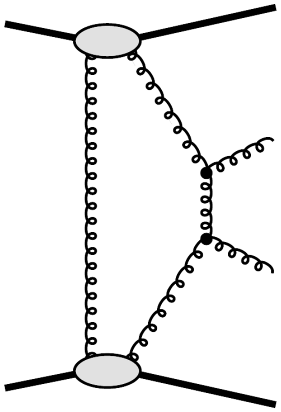


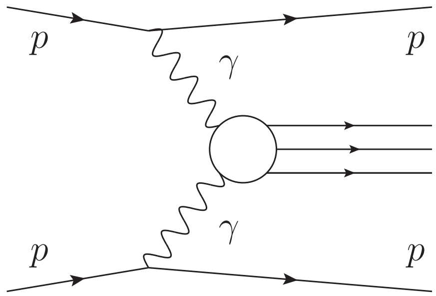


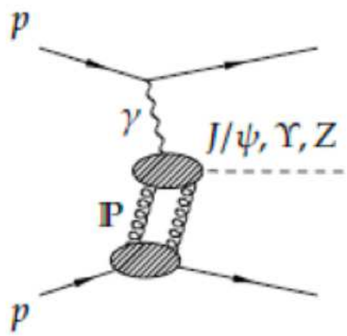


Exclusive diffraction at the LHC



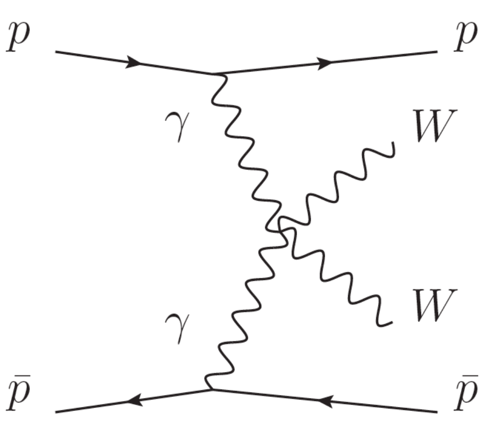


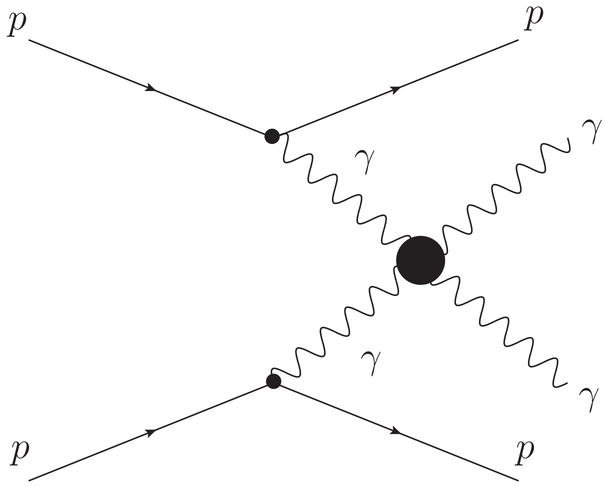




- Many exclusive channels can be studied at medium and high luminosity: jets, χ_C, charmonium, J/Ψ....
- Possibility to reconstruct the properties of the object produced exclusively (via photon and gluon exchanges) from the tagged proton: system completely constrained
- Central exclusive production is a potential channel for BSM physics: sensitivity to high masses up to 1.8 TeV (masses above 400 GeV, depending how close one can go to the beam)
- Exclusive production can be studied both in ep and eA at the EIC

Photon exchange processes and beyond standatd model physics





- Study of the process: $pp \rightarrow ppWW$, $pp \rightarrow ppZZ$, $pp \rightarrow pp\gamma\gamma$
- At high $\gamma\gamma$, WW, ZZ, γZ masses, we are dominated by photon exchange processes (gluon exchanges can be neglected)
- We also have a background free sample: Any observed event is a beyond standard model one
- Rich $\gamma\gamma$ physics at LHC: see E. Chapon, O. Kepka, C. Royon, Phys. Rev. D78 (2008) 073005; Phys. Rev. D81 (2010) 074003; S.Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon, M. Saimpert, Phys.Rev. D89 (2014) 114004 ; S.Fichet, G. von Gersdorff, B. Lenzi, C. Royon, M. Saimpert, JHEP 1502 (2015) 165; S. Fichet, G. von Gersdorff, C. Royon Phys. Rev. Lett. 116 (2016) no 23, 231801 and Phys. Rev. D93 (2016) no 7, 075031; J. de Favereau et al., arXiv:0908.2020.

Conclusion

- Many physics topics studied at HERA can be studied with higher precision at the EIC: only a few examples given here
- Vector meson production/exclusive diffraction: study the interface of perturbative/non-perturbative QCD, saturation, GPDs
- Measurement of parton densities in diffractive events: higher precision, use structure function measurements, jets, charm...
- Study survival effects: using γ-p events as an example
- Study BFKL resummation effects and saturation phenomena: important to have a good coverage in the forward direction in order to measure very forward jets, can be also studied in diffractive events
- Many topics to be studied at the EIC benefitting from the experience at HERA, Tevatron and LHC: importance to have coverage at large rapidities and to detect intact protons in the final state (roman pots)